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Second Language Feedback Abolishes the "Hot Hand" Effect during Even-Probability Gambling

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Research into language–emotion interactions has revealed intriguing cognitive inhibition effects by emotionally negative words in bilinguals. Here, we turn to the domain of human risk taking and show that the experience of positive recency in games of chance—the "hot hand" effect—is diminished when game outcomes are provided in a second language rather than the native language. We engaged late Chinese-English bilinguals with "play" or "leave" decisions upon presentation of equal-odds bets while manipulating language of feedback and outcome value. When positive game outcomes were presented in their second language, English, participants subsequently took significantly fewer gambles and responded slower compared with the trials in which equivalent feedback was provided in Chinese, their native language. Positive feedback was identified as driving the cross-language difference in preference for risk over certainty: feedback for previous winning outcomes presented in Chinese increased subsequent risk taking, whereas in the English context no such effect was observed. Complementing this behavioral effect, event-related brain potentials elicited by feedback words showed an amplified response to Chinese relative to English in the feedback-related negativity window, indicating a stronger impact in the native than in the second language. We also observed a main effect of language on P300 amplitude and found it correlated with the cross-language difference in risk selections, suggesting that the greater the difference in attention between languages, the greater the difference in risk-taking behavior. These results provide evidence that the hot hand effect is at least attenuated when an individual operates in a non-native language.

Key words: **bilingualism; game of chance; decision making; emotion; event-related potentials; binary logistic regression**

Introduction

Recent studies in psycholinguistics and cognitive neuroscience have established effects of language on nonverbal aspects of human cognition such as perception (Thierry et al., 2009; Athanasopoulos et al., 2010), categorization (Boutonnet et al., 2013), and conceptualization (Bylund, 2011; Flecken, 2011).

A critical question is whether language impacts action selection, such as decision making involving rewards, and the cognitive and emotional processes that mediate departures from normatively rational choice (Keysar et al., 2012). Emotion influences decision making (Damasio, 1994; Schwarz, 2000; De Martino et al., 2006) and sometimes leads to suboptimal or even ineffective decisions (Damasio, 1994). Furthermore, mental representations are known to the sensitive to language–emotion interactions (Wu and Thierry, 2012). Thus, emotional aspects of people's decision making, sometimes expressed in suboptimal choices, should depend on language context. Keysar et al. (2012) showed how using a foreign language modulates framing effects and loss aversion when participants choose between risky and certain prospects. These, and other findings (Costa et al., 2014), reveal that operating in a second language moderates peoples' risk attitudes by underweighting larger gains and losses (i.e., influences framing effects; Tversky and Kahneman, 1981) and equalizing the impact of good and bad outcomes (i.e., modulates loss aversion; Tversky and Kahneman, 1992; Kahneman and Tversky, 2000).

This, however, does not tell us how language context influences the encoding of decision outcome to determine future behavior. In real settings, decisions are often sequenced together such that good or bad outcomes of given trials influence subsequent choices (Osborn and Jackson, 1988; Thaler and Johnson, 1990)—even when outcomes are unpredictable or random, as in the case of the "hot hand" fallacy in which the autocorrelation of positive outcomes are wrongly overestimated as reflecting a winning streak (Gilovich et al., 1985; Ayton and Fischer, 2004).

Here, we investigated the modulation of risky behavior by language-based feedback when participants decided to play or

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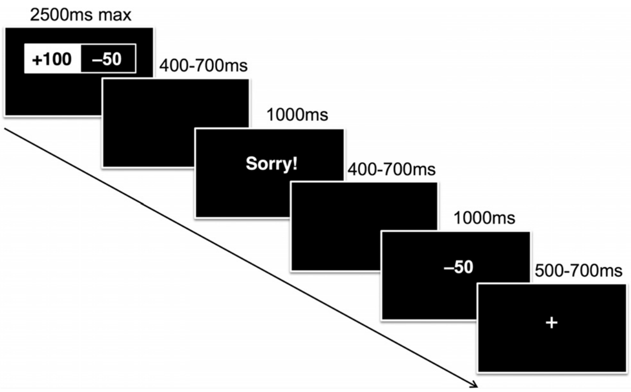

Figure 1. An example of a trial in the computerized risky-choice task.

Table 1. Verbal feedback used in the risky-choice task

English	Chinese
Good!	很好！
Cool!	真行！
Great!	超赞！
Excellent!	太棒了！
Wonderful!	了不起！
Bad!	糟糕！
Sorry!	遗憾！
Sad!	悲催！
Damn!	真可恶！
Terrible!	太惨了！

leave (not play) 50/50 gambles to win small monetary rewards in a game of chance. The choices were presented numerically but outcome was presented using words with positive and negative valence in the participants' first (Chinese) or second (English) language. We modeled the effects of presenting feedback upon participants' subsequent decisions to play. Assuming that the processing of outcomes is altered in the second language, we expected a modulation of risk taking such as hot hand effects in that context.

We used event-related potentials to measure the feedback-related negativity (FRN) known to index the reward value of outcomes (Miltner et al., 1997; Gehring and Willoughby, 2002; Holroyd and Coles, 2002). Since emotional sensitivity differs in the second and first language of bilinguals (Harris et al., 2003), we hypothesized that feedback in English would elicit a smaller FRN because of the lower emotional salience of the second language, in turn affecting risk-taking behavior. We also anticipated a modulation of the P300, since it is often associated with feedback processing (San Martín, 2012), but we had no prediction regarding this effect in relation to language or emotional valence, mainly because of the offset expected in the FRN range.

Materials and Methods

Participants. Sixteen Chinese-English bilingual students (eight males, mean age 23 years, ranging from 20 to 29) were recruited from Bangor University. They received verbal and written study information and gave written informed consent to take part. The experiment was approved by the Ethics Committee of Bangor University. All participants were right-handed, had no vision problems or language disabilities, and reported no history of neurological or psychiatric disorders. Participants had started learning English between the ages of 7 and 15 and had been exposed to English for a mean of 12.5 years by the time of the testing. They rated their own English reading proficiency on average at 6.6 and their Chinese reading proficiency on average at 8.7 (on a scale of 1, not literate, to 10, very literate).

Stimuli. We prepared 30 50/50 mixed outcome prospects or "gambles" of two types: "risky" and "safe." Every gamble consisted of a sign and a number representing the prospective gains or losses displayed to the left or right of a horizontal bar symbolizing the probabilities of winning and losing as 0.5 (Fig. 1), Risky gambles were selected randomly from a list of 25 made up from five gain values (+100, +80, +60, +40, and +20) paired with five loss values (−50, −40, −30, −20, and −10). In addition, five safe gambles were selected randomly from pairings involving the five gain values paired with zero losses.

The 10 English feedback words used were adjectives with high homogenous lexical frequency (mean log10(freq) = 2.29; Coltheart, 1981) and controlled for mean affective valence (positive = 7.44, negative = 3.31; $p < 0.001$) and arousal (positive = 4.19, negative = 4.49, $p > 0.1$; Warriner et al., 2013). Feedback in Chinese was provided using the best translation equivalents of the English adjectives assumed well matched for all characteristics (Table 1). Following completion of the risky-choice task, participants rated the feedback for valence (mean in English = 4.07 ± 0.42, Chinese = 4.11 ± 0.52, $p > 0.1$), arousal (mean in English = 4.76 ± 0.79, Chinese = 4.81 ± 0.90, $p > 0.1$), and familiarity (mean in English = 6.46 ± 0.75, Chinese = 6.32 ± 1.01, $p > 0.05$); there were no statistically reliable differences between language conditions on any measure.

Task and procedure. Gambles were offered in a computerized task administered using E-prime 1.0 software. Participants were asked to indicate whether they wanted to play or not each bet by pressing one of two keys on a keyboard (e.g., a leftward key for "play" and a rightward key for "leave" within 2500 ms, with response sides counterbalanced across participants). If they did not press a key within the allotted time, the words "Time's up" or the equivalent phrase in Chinese (depending on the language block; see below) was displayed in the center of the screen for 1000 ms and the next trial was initiated after a fixation presented for a random duration between 500 and 700 ms. If participants chose to play the gamble, feedback was provided for 1000 ms in the form of a printed word followed by the corresponding numerical outcome, also displayed for 1000 ms. Feedback display was time-locked to the key press when participants took the gamble, and presented with a variable onset from response time, randomized between 400 and 700 ms. Outcome (positive or negative) was randomly generated with a probability of 0.5 on each trial (Fig. 1).

There were eight blocks of 55 trials. In each block, the 25 risky bets were presented twice in a random order together with the five safe bets, each appearing once. These safe bets were used as fillers to monitor participant engagement and were not included in the statistical analysis. For half of the blocks, feedback was given in Chinese and for the other half feedback was given in English. Block order was randomized across participants.

Participants completed a sequence of practice trials until they succeeded in making a play or leave decision within 2000 ms in 8 of 10 trials. Participants were paid a basic participation fee (£15) for completing the experiment. In addition, they were told that 40% of the gambles they chose to play would be selected randomly and used to adjust their final participant fee. Each point accumulated equated to one British penny and participants were instructed to earn as much money as possible.

Written information about the experiment including consent form, debriefing information, and language inventory were received in English. During the experiment, participants received either English or Chinese instructions depending on the feedback language of each particular block. As for the word-rating task after the experiment, instructions were presented in Chinese.

EEG recording. Electrophysiological data were recorded in reference to Cz at a sampling rate of 1 kHz from 64 Ag/AgCl electrodes connected according to the extended 10–20 convention. Impedances for all electrodes were kept below 5 kΩ. Electroencephalogram activity was filtered on-line bandpass between 0.1 and 200 Hz and refiltered off-line with a 25 Hz low-pass, using a zero-phase shift digital filter. Eye blinks were mathematically corrected, and remaining artifacts were manually dismissed (Gratton et al., 1983). There was a minimum of 30 valid epochs per condition in every subject. Epochs ranged from −100 to 1000 ms after the onset of feedback. Baseline correction was performed in reference to prestimulus activity, and individual averages were digitally re-referenced to the global average reference. ERP data were collected simultaneously to behavioral data.

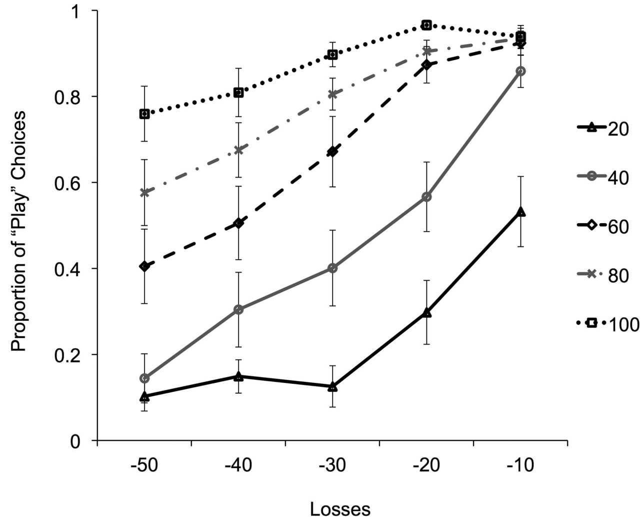

Figure 2. Overall proportion of risky choices as function of loss for each size of gain. Error bars depict SEs.

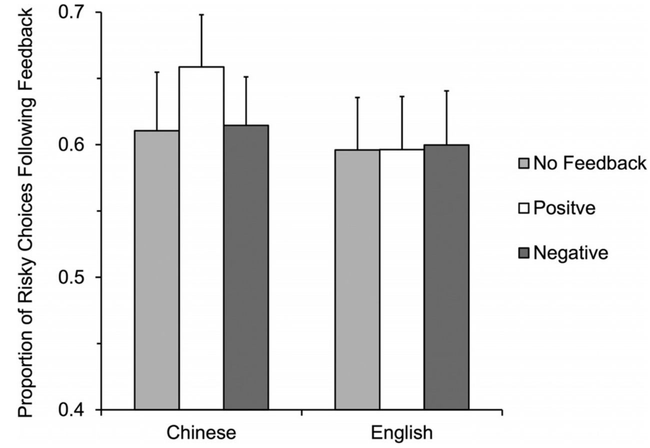

Figure 3. Proportionate choice of playing gambles in Chinese or English context as a function of feedback of preceding choice (no feedback as the outcome of leaving the gamble, positive feedback, and negative feedback). Error bars depict SEs.

ERP analysis. Peak detection was performed automatically, time-locked to the latency of the peak at the electrode of maximal amplitude on the grand-average ERP. Temporal windows for peak detection were determined based on variations of the global field power measured across the scalp (Picton et al., 2000). We also analyzed ERP data by means of pairwise millisecond-by-millisecond comparisons between conditions considered significant when differences were above threshold ($p < 0.05$ for > 30 ms over a minimum of nine clustered electrodes; Rugg et al., 1993; Thierry et al., 2003). As a result, the FRN was defined as the mean amplitude in the 250–350 ms time window following feedback onset at nine electrodes over the frontocentral area (i.e., AF3, F3, FC1, AFz, Fz, FCz, AF4, F4, and FC2) where the FRN is classically found and displays maximal sensitivity (Wu and Zhou, 2009; Kobza et al., 2011; San Martín, 2012; Walsh and Anderson, 2012). The P300 was measured as the mean amplitude in the 350–650 ms time window after feedback over nine centroparietal electrodes (i.e., FC1, C1, CP1, FCz, Cz, CPz, FC2, C2, CP2) where the P300 is classically observed and displays maximal sensitivity (Fosker and Thierry, 2005; Tainturier et al., 2005; Lallier et al., 2010; Wu and Thierry, 2012). Differences between conditions were analyzed using repeated-measures ANOVAs. The Greenhouse–Geisser correction for nonsphericity was applied as required and significant interactions involving the electrode factor were verified using a normalization procedure as recommended by Picton et al. (2000).

Behavioral data analysis. First, participants' play or leave decisions for each gamble were analyzed with binary logistic regression using the predictors language of feedback (with Chinese as the referent), the magnitude of prospective gains, the magnitude of prospective losses, and the outcome of preceding choice modeled as a categorical variable (winning or losing outcome with leave choices as the referent). Second, to test whether the language of feedback influenced the impact of the last outcome, we then included the interaction between language and outcome of preceding choice as an interaction term. Reaction times were examined with equivalent standard regression analysis. Participants were modeled with random effects. β-values are reported with their SEs and tested at $p < 0.05$.

Results

Behavioral results

First, we tested the main effects of prospective gain and loss magnitudes. Participants tended to play more gambles as the magnitude of prospective gains increased ($\beta = 0.92(0.03)$, $p < 0.0001$). In contrast, they played fewer gambles with larger prospective losses ($\beta = -0.63(0.03)$, $p < 0.0001$; Fig. 2). With regards to the language main effect, participants played fewer gambles in the English compared with the Chinese context ($\beta = -0.17(0.06)$, $p < 0.01$), indicating diminished risk taking when feedback was given in the second language.

As expected, wining on the previous trial increased participants' risk-taking behavior on the current trial ($\beta = 0.21(0.08)$, $p < 0.01$). Losing had little impact ($\beta = 0.10(0.08)$, $p > 0.1$). However, adding the interaction between language and outcome valence showed that winning on the previous trial increased the likelihood of subsequent decisions to play the gambles when the outcomes had been presented in Chinese but not English ($\beta = -0.48(0.15)$, $p < 0.01$; Fig. 3). To examine whether or not the observed language main effect and language-by-valence interaction were modulated by either time of presentation (i.e., trial sequence) or language switch (i.e., the alternation of language of feedback between experimental blocks), we added language by time of presentation, language by valence by time of presentation, language by language switch, and language by valence by language switch interactions as regressors in the analysis and found no significant effects of either time of presentation or language switch in any of these analyses (all $ps > 0.1$).

Participants spent less time deliberating about their decisions as the gains increased ($\beta = -17.28(1.79)$, $p < 0.0001$), but took more time with increasing losses ($\beta = 5.10(1.79)$, $p < 0.0001$). Participants were overall slower making their decisions in the English relative to the Chinese feedback condition ($\beta = 20.72(8.26)$, $p < 0.05$). Participants' responses were also faster when receiving either positive ($\beta = -27.10(8.74)$, $p < 0.01$) or negative ($\beta = -27.01(8.71)$, $p < 0.01$) compared with no feedback when having decided not to gamble on the previous trial. Participants' reaction times were not associated with the interaction between language and outcome valence of the previous choice (positive feedback English vs Chinese: $\beta = 4.89(12.29)$, $p > 0.1$; negative feedback English vs Chinese: $\beta = 0.05(12.21)$, $p > 0.1$). There was no interaction between language and time of presentation ($\beta = 0.03(0.05)$, $p > 0.1$).

Finally, we investigated potential effect of self-rated reading proficiency in English and Chinese by conducting regressions separately for play-or-leave choices and reaction times, after adding either of the following two interactions as regressors: (1) the interaction between Language (using English as referent) and

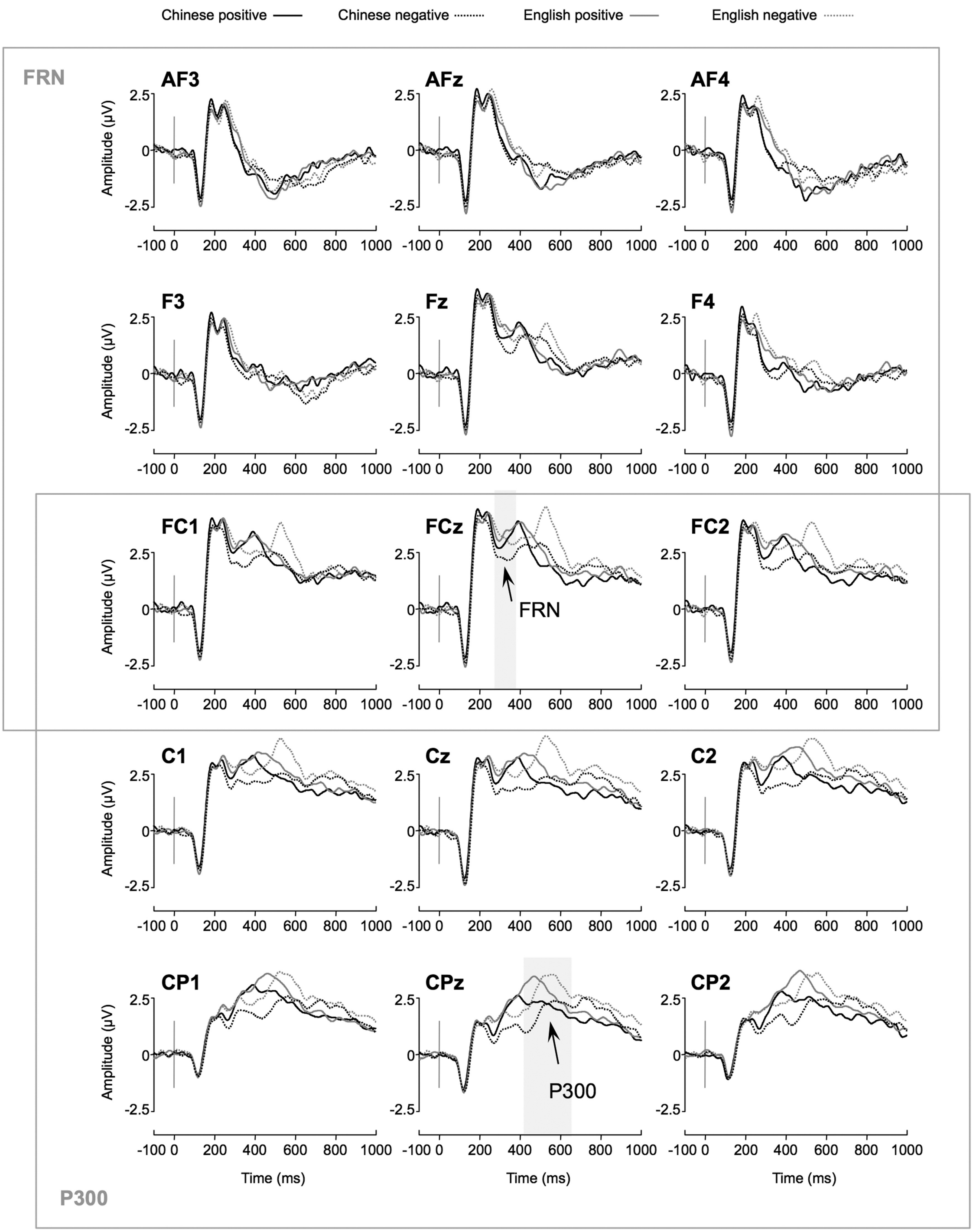

Figure 4. ERPs elicited by emotional feedback words in Chinese and English. Waveforms depict brain potential variations at recording sites over the nine electrodes expected to ideally capture the FRN (AF3, AFz, AF4, F3, Fz, F4, FC1, FCz, and FC2) and the nine electrodes expected to capture the P300 effect (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, and CP2). Note: The shaded areas highlighting the FRN and P300 are approximative; for accurate analysis time-windows, see Materials and Methods.

Chinese reading proficiency and (2) the interaction between Language (using Chinese as referent) and English reading proficiency. As regards play or leave choices, neither Chinese nor English reading proficiency had a significant impact on the proportionate risky choices between languages (proficiency in Chinese: $\beta = 0.06(0.05)$, $p > 0.1$, proficiency in English: $\beta = 0.10(0.06)$, $p > 0.05$). As regards reaction times, however, reading proficiency in Chinese contributed significantly in the Chinese relative to the English context ($\beta = 22.12(2.12)$, $p < 0.01$) and so did reading proficiency in English in the English relative to the Chinese context ($\beta = 5.20(2.41)$, $p < 0.05$). We also tested whether cross-language differences in reading proficiency would correlate with the difference in the proportion of risky choices and the difference in reaction times between language contexts, respectively. We found no significant correlations (proportion of risky choices: $r = 0.273$, $p > 0.1$, two-tailed; reaction times: $r = 0.197$, $p > 0.1$, two-tailed). These correlations did not reach significance when tested with one-tailed tests either.

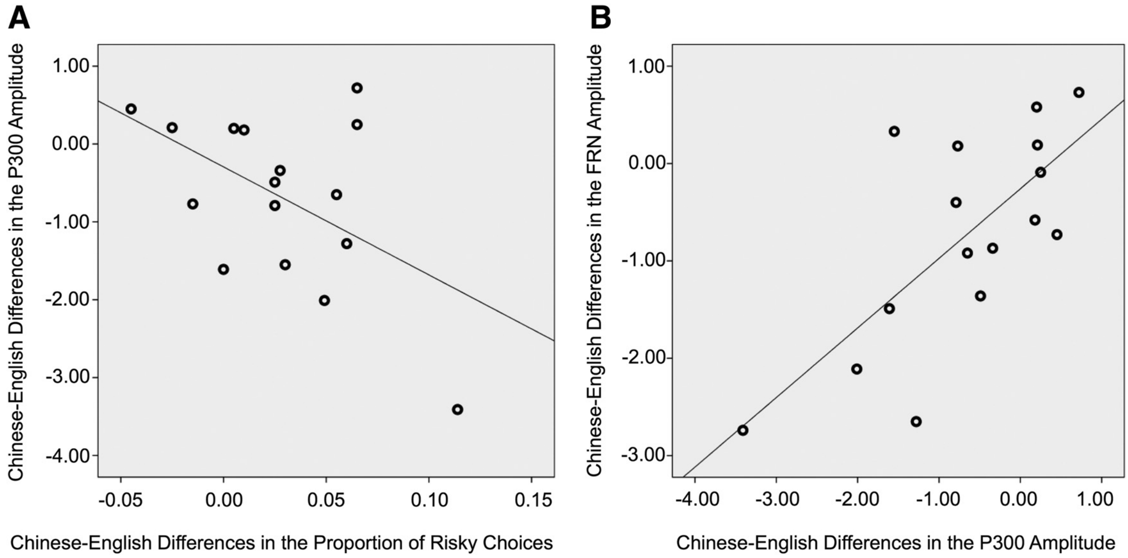

Figure 5. Significant correlations. ***A***, Correlation between cross-language differences in the P300 amplitude and the proportion of risky choices. ***B***, Correlation between cross-language differences in the FRN and the P300 amplitude. All cross-language differences were calculated by subtracting English from Chinese.

ERP results

Mean amplitudes of ERPs time-locked to the onset of feedback words were subjected to repeated-measures ANOVAs in the range of the FRN and the P300 using language, valence, and electrode as within-subject factors (Fig. 4).

The FRN response was more negative following Chinese words compared with English equivalents ($F_{(1,15)} = 7.65$, $p < 0.05$). Conversely, the P300 response was significantly enhanced following English compared with Chinese ($F_{(1,15)} = 6.66$, $p < 0.05$). Language-by-valence interactions were significant in both the FRN and the P300 ranges: $F_{(1,15)} = 7.26$, $p < 0.05$ and $F_{(1,15)} = 5.27$, $p < 0.05$, respectively. Pairwise comparisons with a Bonferroni adjustment revealed that the FRN displayed a larger difference following winning outcomes compared with losing outcomes in the Chinese but not the English condition (Chinese–English = 1.02 μV, $p < 0.01$). The P300 showed the reverse pattern, i.e., a larger valence effect in English compared with Chinese (Chinese–English = -0.95 μV, $p < 0.01$).

We also found significant valence by electrode interactions in the FRN and P300 ranges. However, these interactions did not survive the normalization procedure recommended by Picton et al. (2000) and were thus not considered further.

Correlational findings

To confirm the modulation of risk-taking behavior by language of operation, Pearson correlations were computed between cross-language differences in ERP amplitude and differences in the proportion of trials on which participants played the gambles. The analysis showed that the difference in the proportionate gambles in English and Chinese correlated negatively with the P300 amplitude difference between languages ($r = -0.51$, $p < 0.05$, two-tailed), indicating that the larger the P300 cross-language difference, the larger the difference in risky-choice proportion (Fig. 5*A*). On the other hand, correlation between the risky-choice proportion difference and the FRN amplitude difference failed to reach significance ($r = -0.44$, $p = 0.089$, two-tailed), but the FRN and P300 amplitude differences between languages also correlated significantly with each other ($r = 0.71$, $p < 0.01$, two-tailed; Fig. 5*B*).

Discussion

The present study investigated how emotionally marked feedback in a first or second language affects risk-taking behavior. We developed a simple paradigm offering gambles with even probabilities of winning and losing. Overall, participants chose faster and played more gambles for larger gains and smaller losses, confirming that their choices were sensitive to risk. Critically, we found a main effect of language, such that feedback in the second language led to fewer gambles and slower responses overall compared with feedback in the native language. It is noteworthy that none of the participants had a background in psychological research or experience with psychological experiments. Some of the participants overtly manifested surprise when they read the debriefing information, which suggests that participants were unaware of the rationale behind the experiment.

This finding extends our understanding of language–cognition interactions by showing that the language used to present decision outcomes influences decision making under risk. In particular, the binary logistic regression identified positive feedback as driving the difference between the two language contexts. Feedback for preceding gains presented in Chinese led to more risk taking but, when positive feedback was provided in English, no such effect was observed. We contend that this demonstrates a reduction in the hot hand effect or experienced positive recency in the second language, compared with a native language context (Keysar et al., 2012; Wu and Thierry, 2012). This process appears to be implicit since outcome valence effects upon participants' risky choices were found in the absence of any difference in the affective ratings of the words by participants and was independent of adaptation to the affective valence of the feedback words. Strikingly, the effect of positive feedback in the native language was found despite clear disclosure that trials were independent of one another and that overall gains would be calculated from a random selection of trials at the end of the experiment. To our knowledge, this is the first demonstration that the hot hand fallacy, or experienced positive recency, is enhanced in the native compared with a second language.

Our results provide a different but complementary insight into the phenomenon previously reported by Keysar et al. (2012), namely, that decision-making biases can be normalized in a foreign language. Indeed, while the findings of Keysar et al. (2012) show a reduction of the framing effects and loss aversion in a foreign language context, ours reports a reduction of the hot hand effect when choice outcomes are signaled in a second language. There are several ways to understand hot hand effects. These include the faulty rejection of sequences of positive outcomes as "representative" of randomness (Gilovich et al., 1985) or overestimated autocorrelation in the context of human judgments or skills (Ayton and Fischer, 2004), possibly as a sometimes adaptive heuristic (Burns, 2004). However, Keysar et al.'s (2012) study and ours have in common the finding that the activation of these cognitive biases in risky decision making is diminished in the medium of a foreign language, perhaps reflecting repressed access to affective or reinforcement valence (Wu and Thierry, 2012).

Differential neural processing of feedback in the two languages was reflected in the mean amplitudes of two electrophysiological correlates, the FRN and the P300, known to be modulated by feedback. The FRN was significantly amplified for Chinese words relative to their second language equivalents. That is, the emotional salience of words, in the absence of difference between languages in terms of valence and arousal, varied neurophysiologically as a function of language. Despite previous prediction of such effects, this amplitude difference between ERPs elicited by emotional words in a first and a second language has not been reported before. Employing a visual lexical decision task, for instance, Conrad et al. (2011) observed no cross-language modulation by emotional words of the early posterior negativity or late positive complex, two ERP components sensitive to emotional valence in native language processing (Opitz and Degner, 2012). In the neuroimaging domain, Eilola et al. (2007) also failed to find any difference between activation patterns elicited by emotional words in the first and second language. We contend that a monetarily motivated gambling task is particularly affective and therefore well suited to elicit cross-language differences in emotional processing leading to differences in risk-taking behavior.

We also observed a significant difference in P300 amplitude between the two language contexts with a more pronounced response for English than Chinese feedback. This P300 difference correlated with cross-language differences in the proportionate choice of play trials, indicating that when participants took into account differences between languages, they tended to manifest different gambling behavior. Indeed, the larger the P300 amplitude elicited by feedback in English compared with Chinese, the greater the difference in the proportion of risky decisions between Chinese and English. In other words, when the language of feedback is attended, the foreign language effect on risk taking becomes more pronounced.

Moreover, cross-language differences in P300 amplitude highly correlated with differences in FRN amplitude. Language-by-valence interactions in the FRN and P300 amplitude showed a reverse trend: the FRN response to negative feedback was significantly reduced for English compared with Chinese and the P300 response to negative feedback was significantly reduced for Chinese compared with English. While interpretation of such interactions can only be hypothetical, especially considering the relatively weaker statistical power involved, these findings suggest that the P300 mean amplitudes are strongly influenced by offsets arising in the FRN window and therefore that FRN and P300 amplitude overall reflect cognitive processes that are functionally related. A deep interpretation of this correlation awaits further investigation with a dedicated paradigm.

Conclusion

Overall, our study demonstrates a tangible effect of language context on risk-taking behavior, one that is spontaneous and driven by fast, automatic language processing of feedback words. It is quite remarkable that such effects can arise in experimental conditions where context is manipulated merely by feedback provided in the form of very concise expressions (single words in English and a few characters in Chinese). Also the overall trend shows greater engagement in gambling in a game of chance for positive feedback in the native language, possibly associated with greater trust in the native language and a deep relationship between language of operation and other domains of cognition such as emotion. This novel result sheds more light onto language–thought interactions in the wake of other linguistic relativity studies in the domain of color (Thierry et al., 2009; Athanasopoulos et al., 2010) and object categorization (Boutonnet et al., 2013).

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